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C.T. Liu (AFRL/PRSM)

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AFRL/PRSM
10 East Saturn Blvd.
Edwards AFB CA 93525-7680

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Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.

AFOSR Program Review

8 Sept. 2003

C. T. Liu

AFRL/PRSM

Edwards AFB CA.

Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.

- Objectives:
  - Obtain a fundamental understanding of the tensile and fracture behavior of nano composite materials.
  - Develop a microstructure and statistical based technology to evaluate the inherent material quality.
- State of the Art:
  - Uniaxial tensile and combustion characteristics tests were conducted.
  - Fracture behavior not studied.
- Approaches:
  - Multi-scale experimental, analytical, and numerical modeling analyses
  - Damage mechanics, experimental mechanics, fracture mechanics, and statistical mechanics
- Applications:
  - Strategic and tactical missile systems.

Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.

- Past Year Accomplishments:
  - Conducted strain measurements on two matrix materials (Solithane 113 and TPEG) and a composite material (TPEG and 10% by weight of 6 micron AL particles).
  - Investigated the failure mechanisms in the three materials.
  - Investigated microstructural change and damage mechanisms in a solid propellant under incremental strain conditions.
  - Conducted computer simulation of damage initiation and evolution processes in a solid propellant.
- Research Payoff:
  - Provide a fundamental understanding of the role of nano size particles on the deformation and damage processes as well as crack growth behavior.
  - Provide guidance for developing high strength nano composite materials.
- Related Research Program:
  - SERDP Green Missile Program (P.I. Dr. T. Hawkins; AFRL/PRSP)

Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.

<u>Uniqueness of Research:</u>

- Unique Material (dual function and highly filled multi-size particles material).
- Account for microstructurral effect on tensile and crack growth behavior.
- Account for local time-dependent behavior in crack growth simulation.
- Multi-scale microstructure controlling factors for damage and crack growth.
- Bridge the gap between meso and macro analyses.

Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.

Success Story:

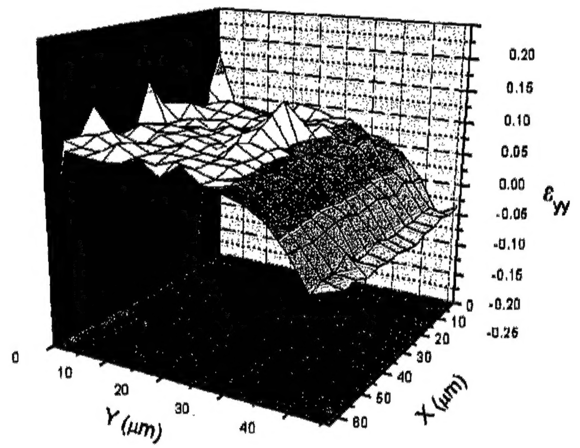
- There is no success story yet, because this four-year program just started in FY 03.

Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.

Applications:

- The developed techniques can be used to formulating high performance solid propellants for future strategic and tactical missile systems.

Strain Distributions at 1500X
(Solthane 113)



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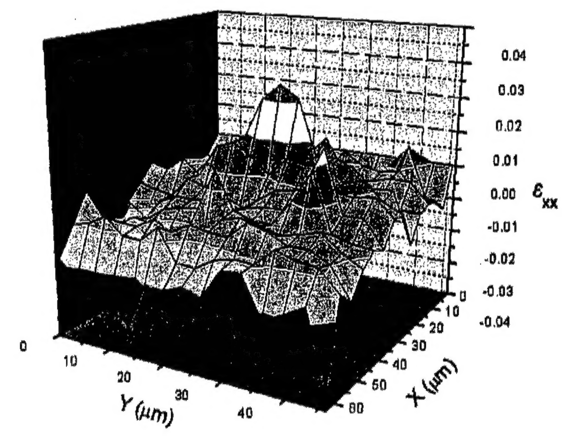

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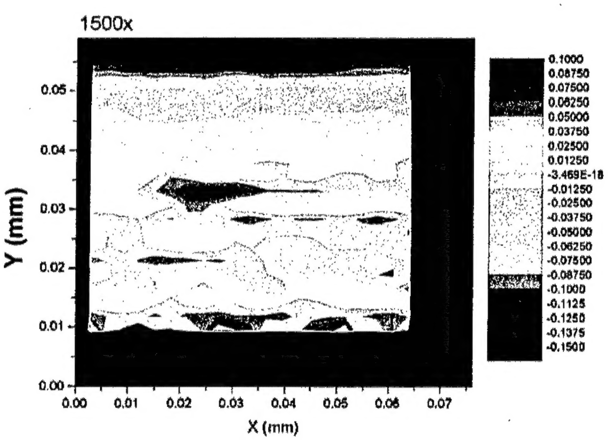

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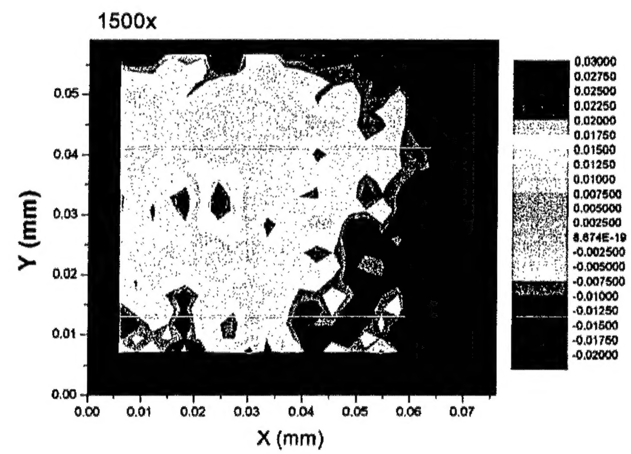

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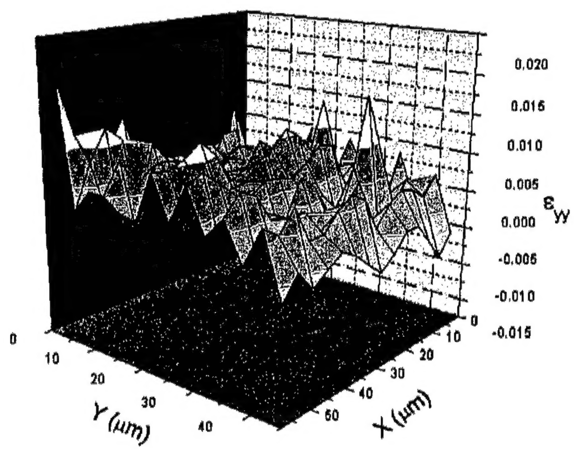
Strain Distributions at 1500X
(TPEG)



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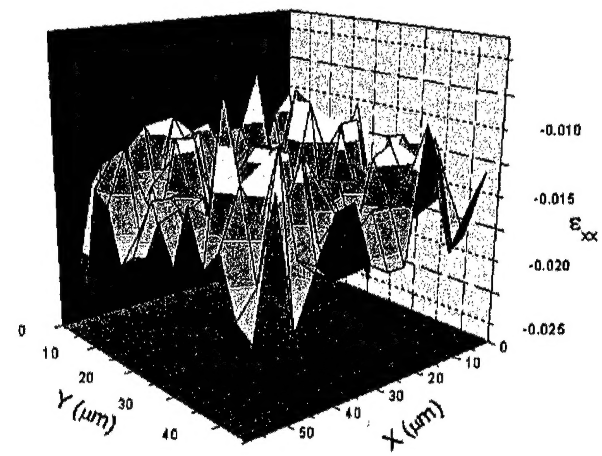

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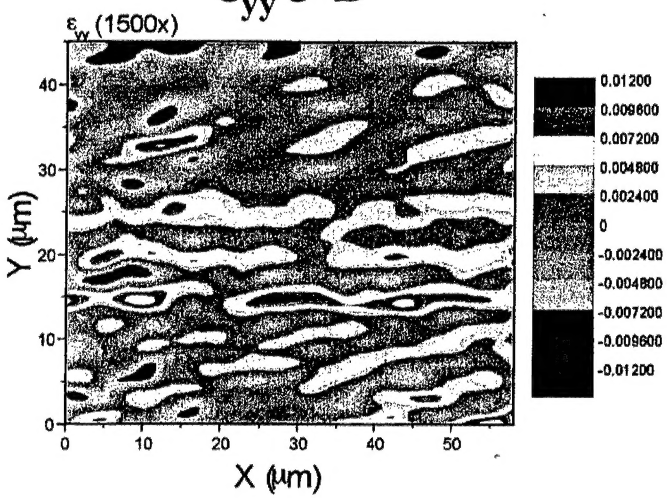

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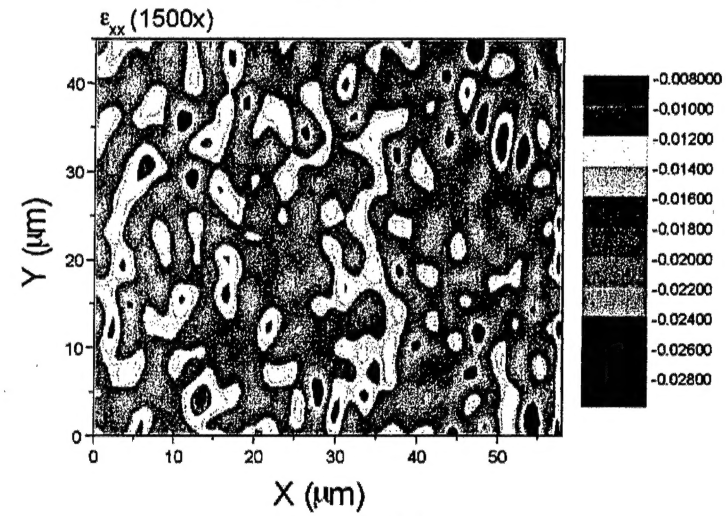

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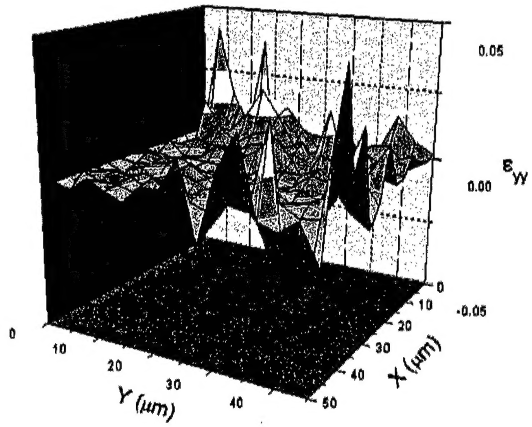
Strain Distributions at 1500X
(Composite Material)



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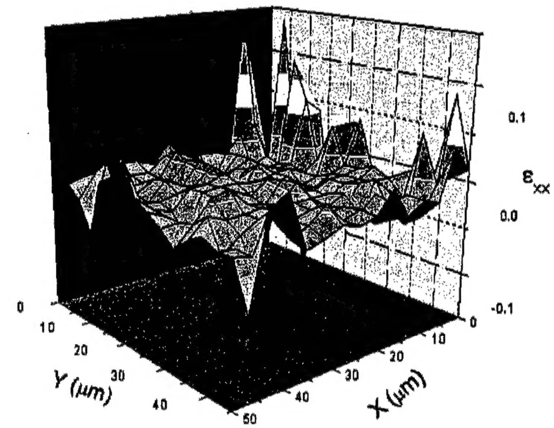

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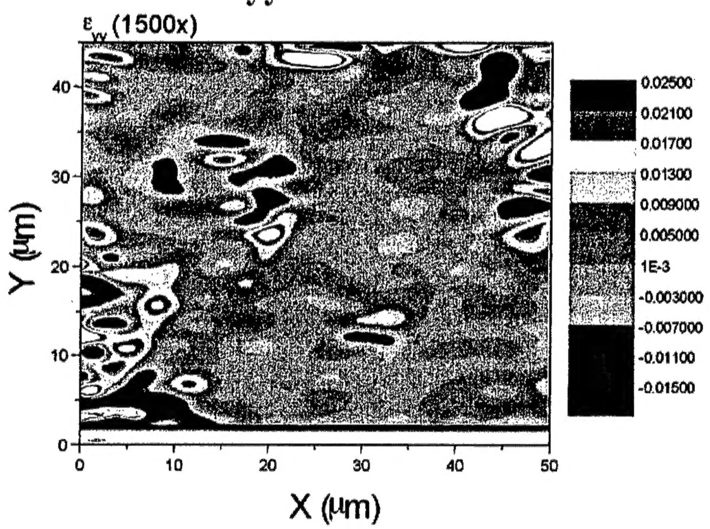

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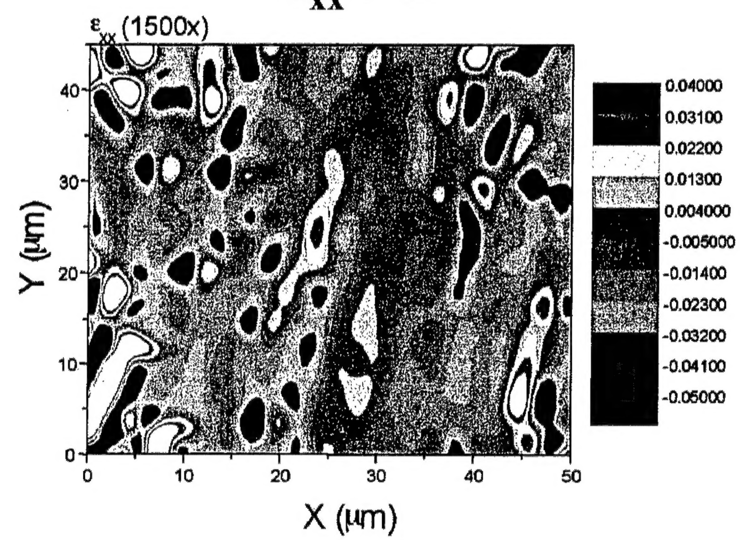

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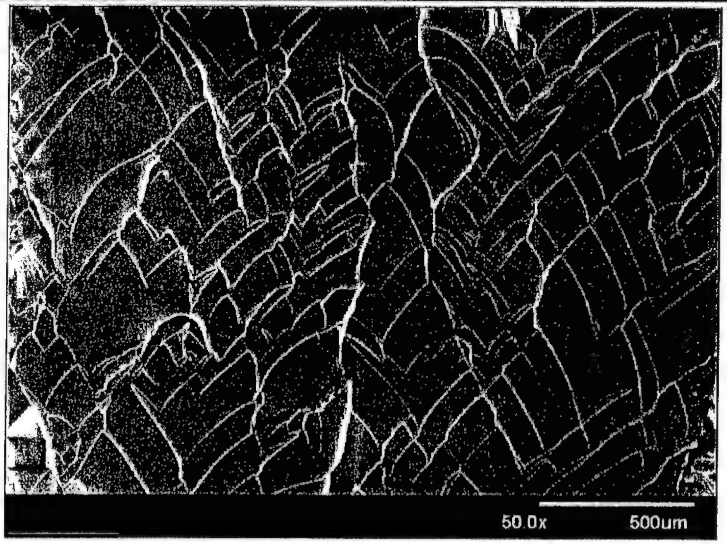
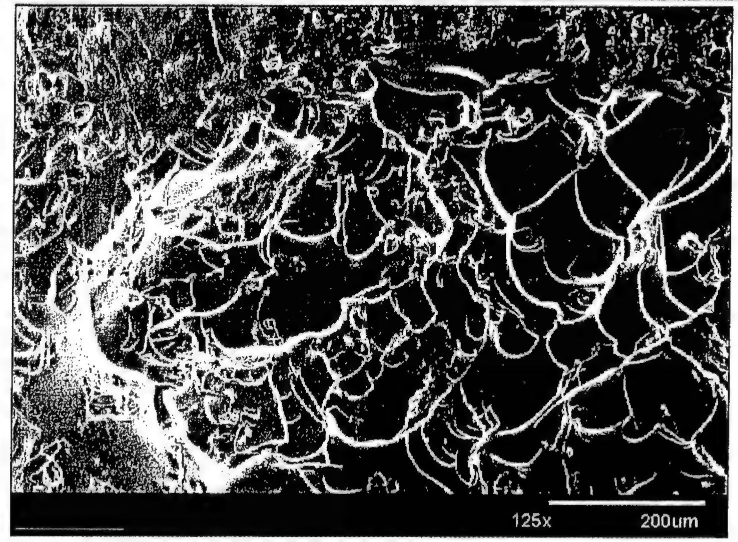
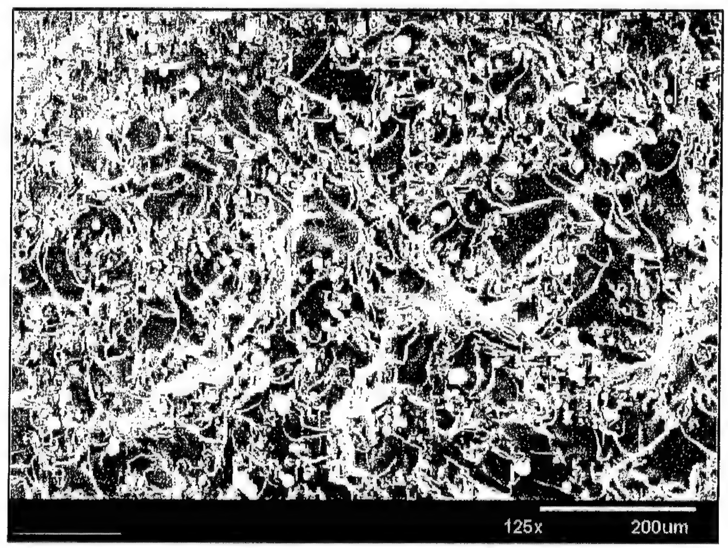
Fracture Surfaces



(Solithane 113)

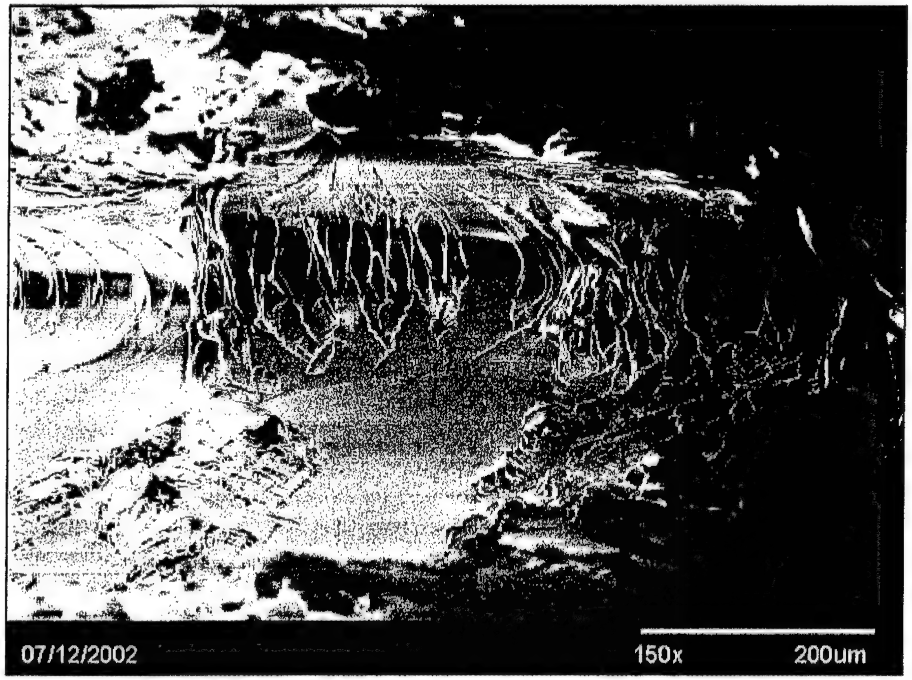


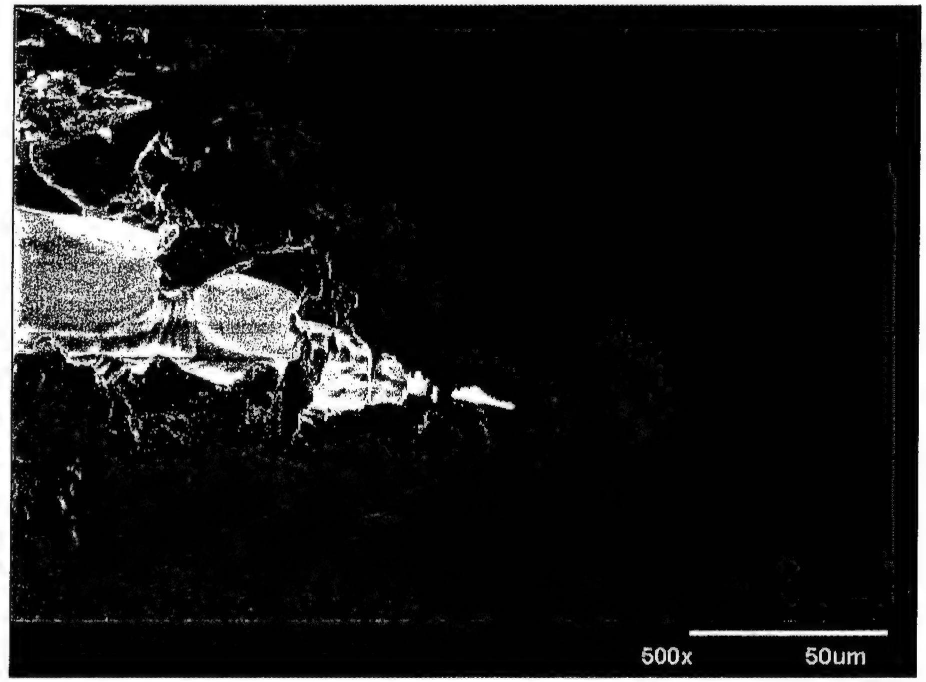
(TPEG)



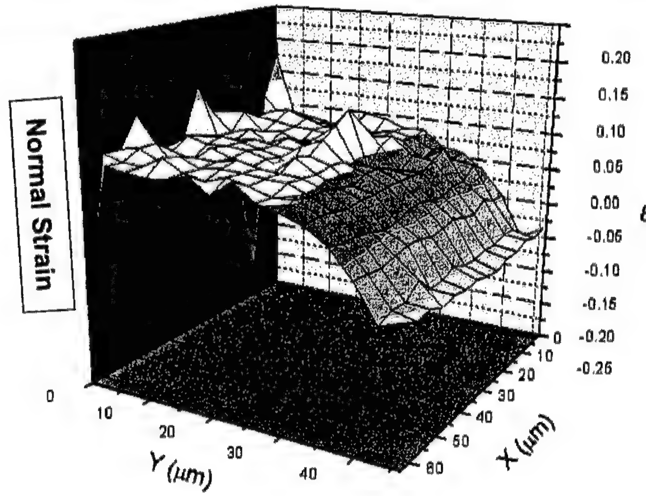
(Composite Material)

Local Deformation and Failure Mechanisms (Solithane 113)

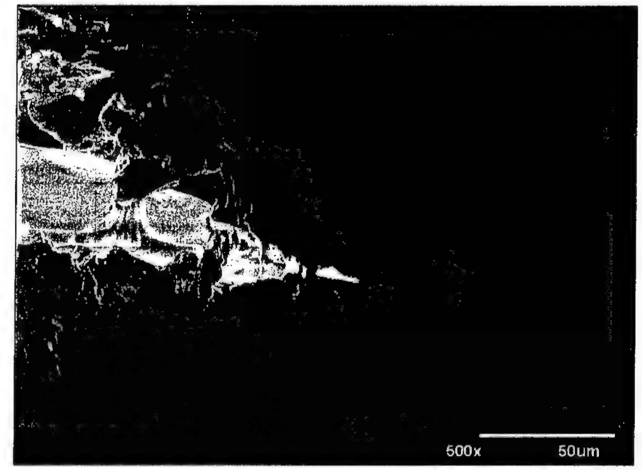




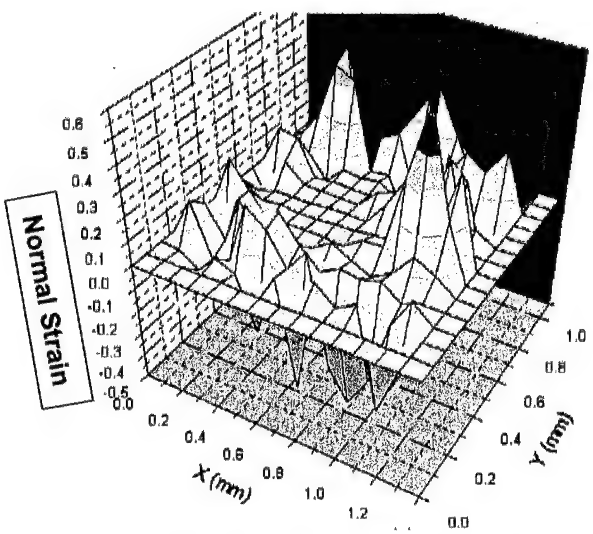
Mechanisms and Strain Distribution (Solithane 113 and a Solid Propellant)



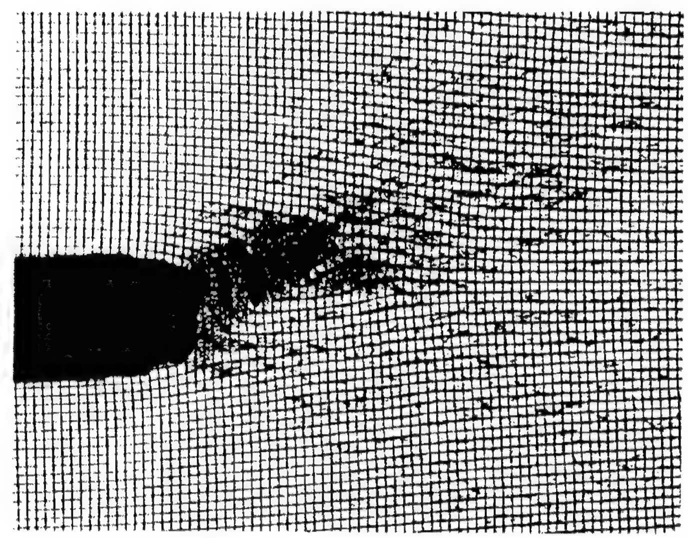
Solithane 113



Solithane 113

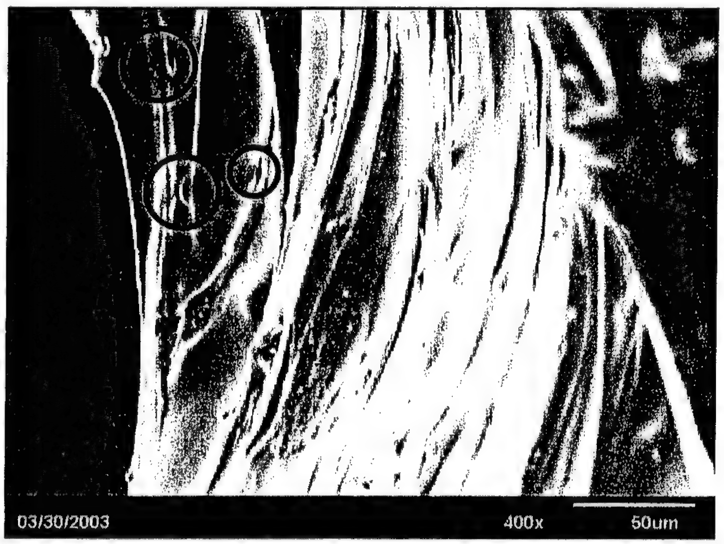


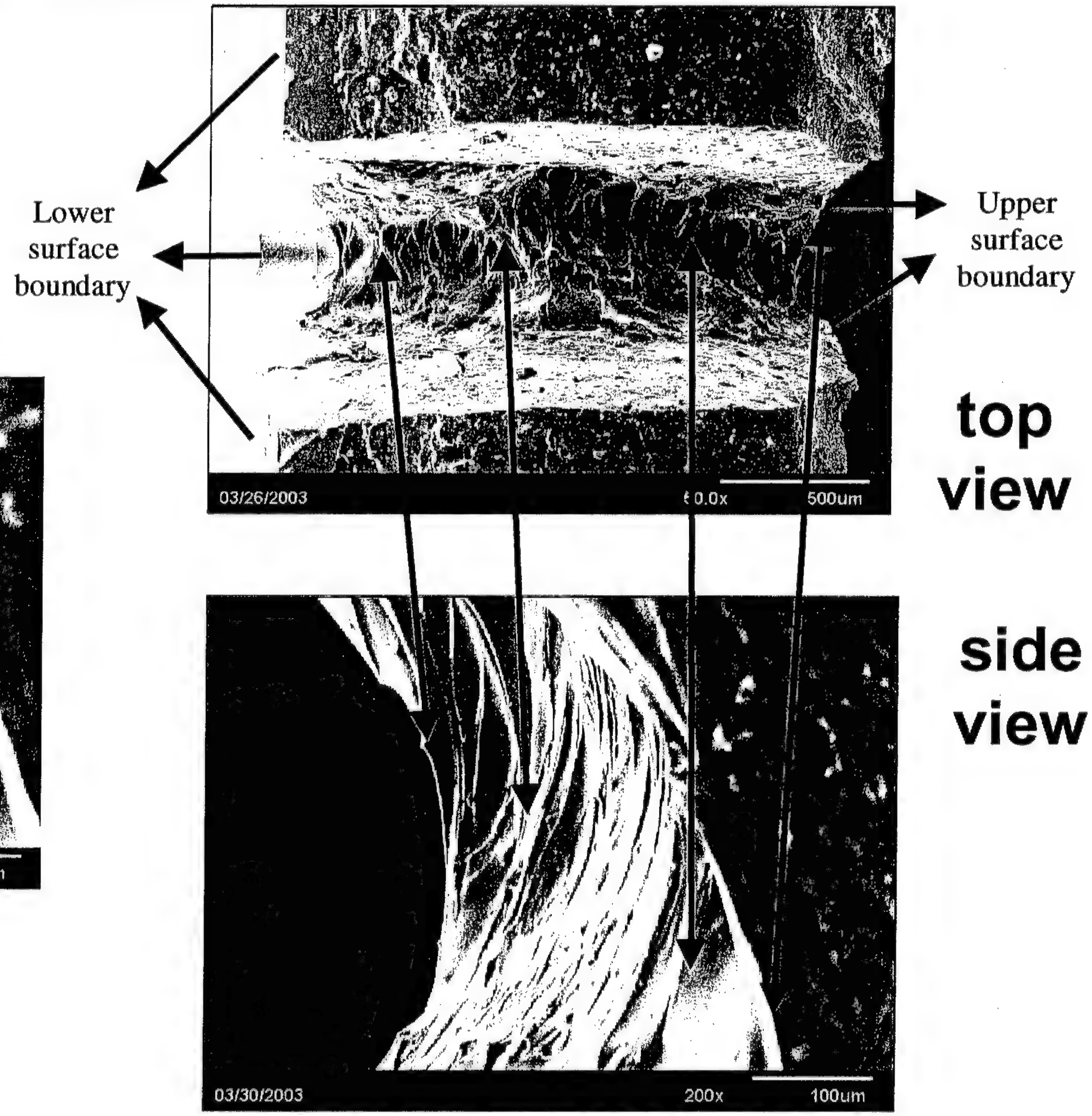
Solid Propellant



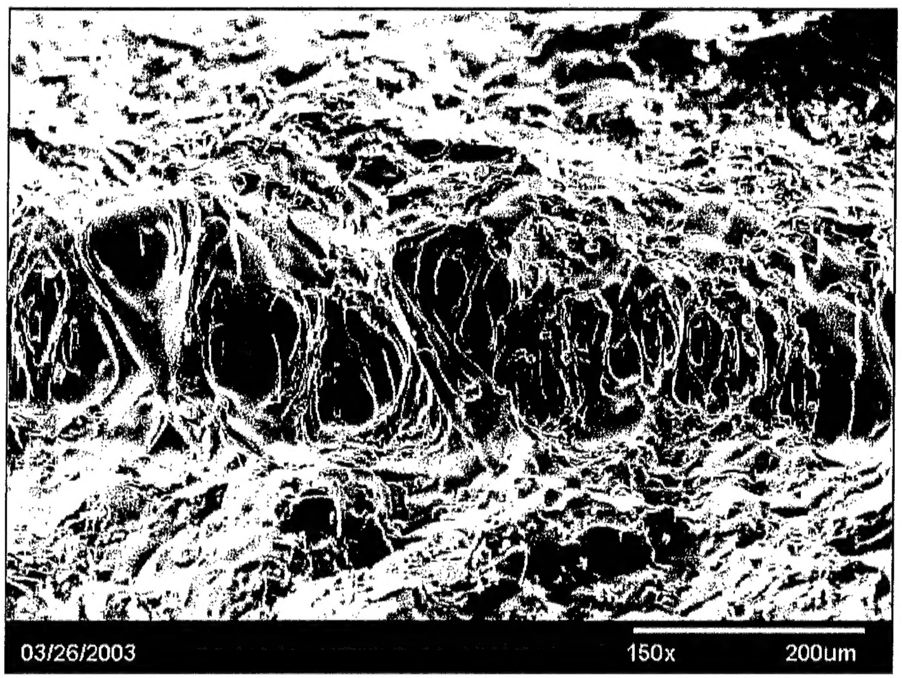
Solid Propellant

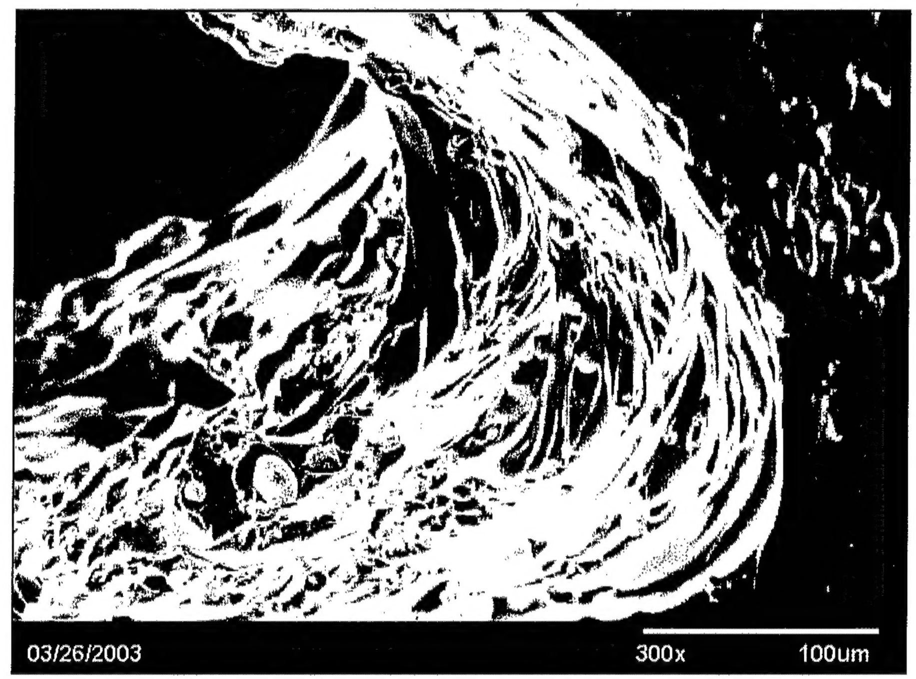
Local Deformation and Failure Mechanisms at Crack Tip (TPEG)



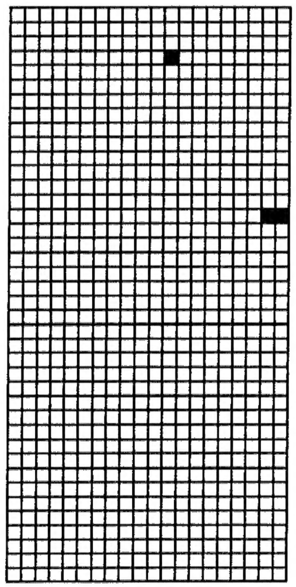


Local Deformation and Failure Mechanisms at Crack Tip (Composite Material)

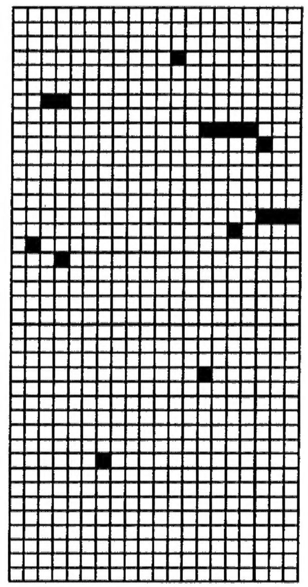




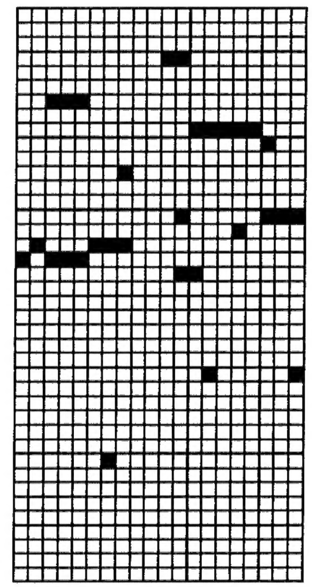
Numerical Simulation on Damage Initiation and Evolution



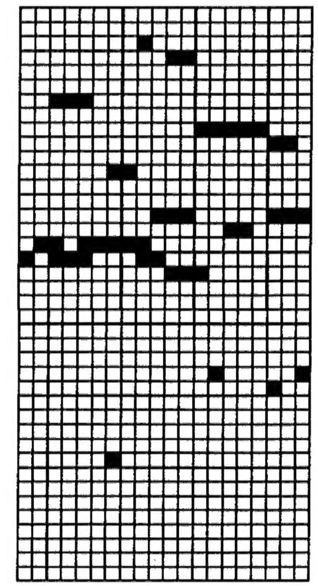
applied strain level
0.109 [m/m]



applied strain level
0.121 [m/m]



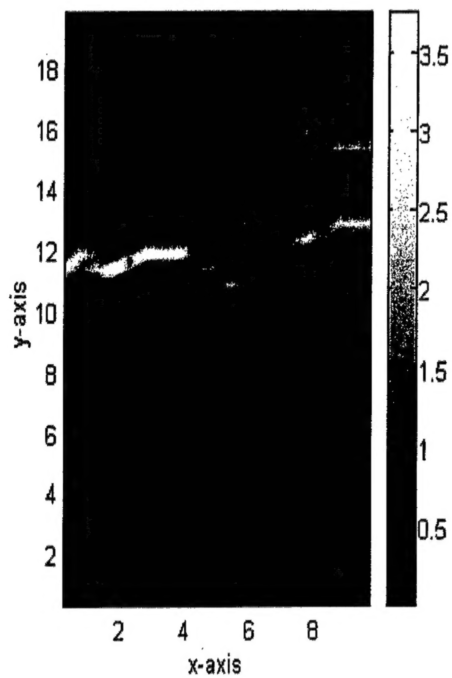
applied strain level
0.128 [m/m]



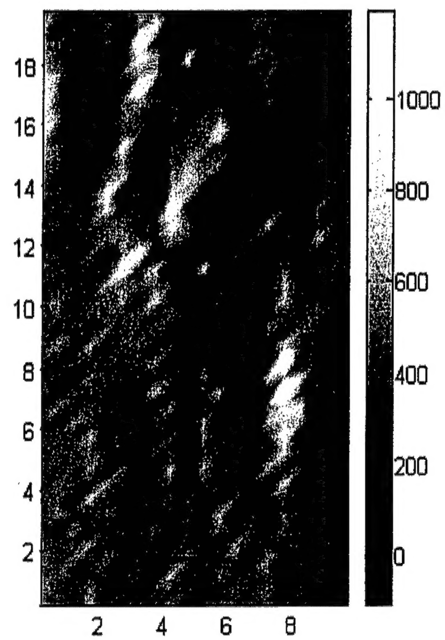
applied strain level
0.134 [m/m]

- Based on meso-macromechanical multi-level analyses, the simulated damage processes under a constant strain rate condition compares well with experimental observation.
- The coalescence of neighboring non-propagating crack results in breakage of the specimen.

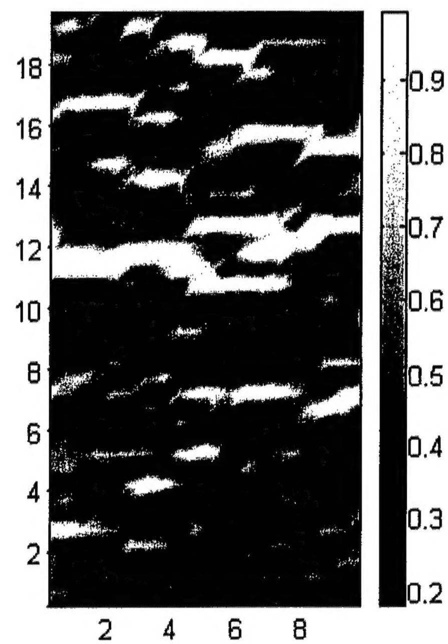
Distributions of Damage, Macro-Normal Strain and Macro-Normal Stress Prior to Specimen Fracture



Macro-Normal Strain



Macro-Normal Stress



Damage Distribution

Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.

Conclusions:

- Microstructure has a significant effect on the strain fields on the meso scale.
- The local deformation mechanisms (large displacement and ligament formation) near the crack tip for the three material studied are similar but the damage mechanisms are different.
- Base on the multi-scale analysis, the damage initiation and evolution processes compare well with experimental observation.
- Based on the multi-scale analysis, the damage distribution prior to specimen fracture is similar (different) to the macro strain distribution (macro stress distribution).
- The developed multi-scale analysis technique is a promising technique to model and simulate the microstructural effect on damage initiation and evolution processes in a solid propellant.